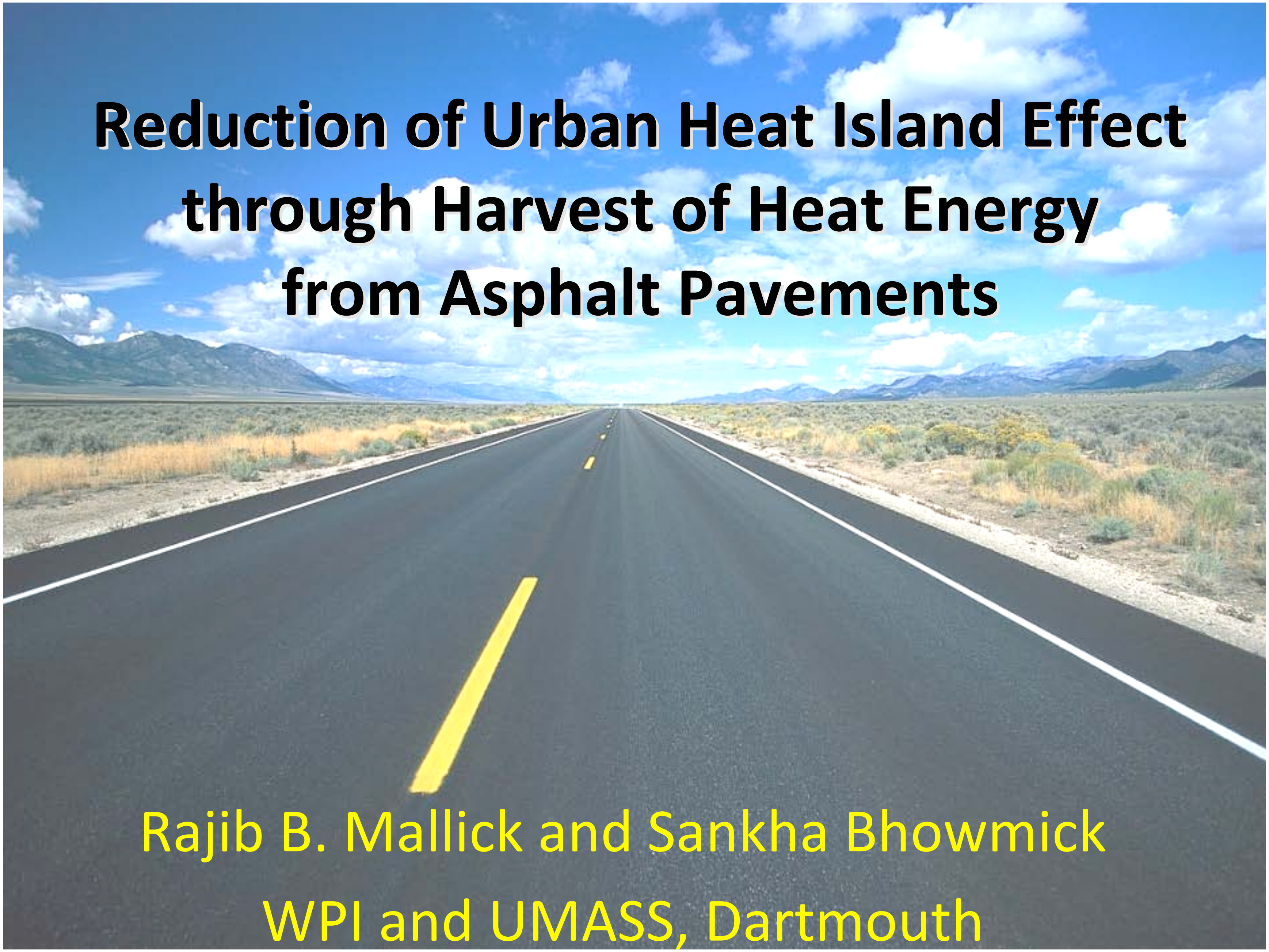


Reduction of Urban Heat Island Effect through Harvest of Heat Energy from Asphalt Pavements

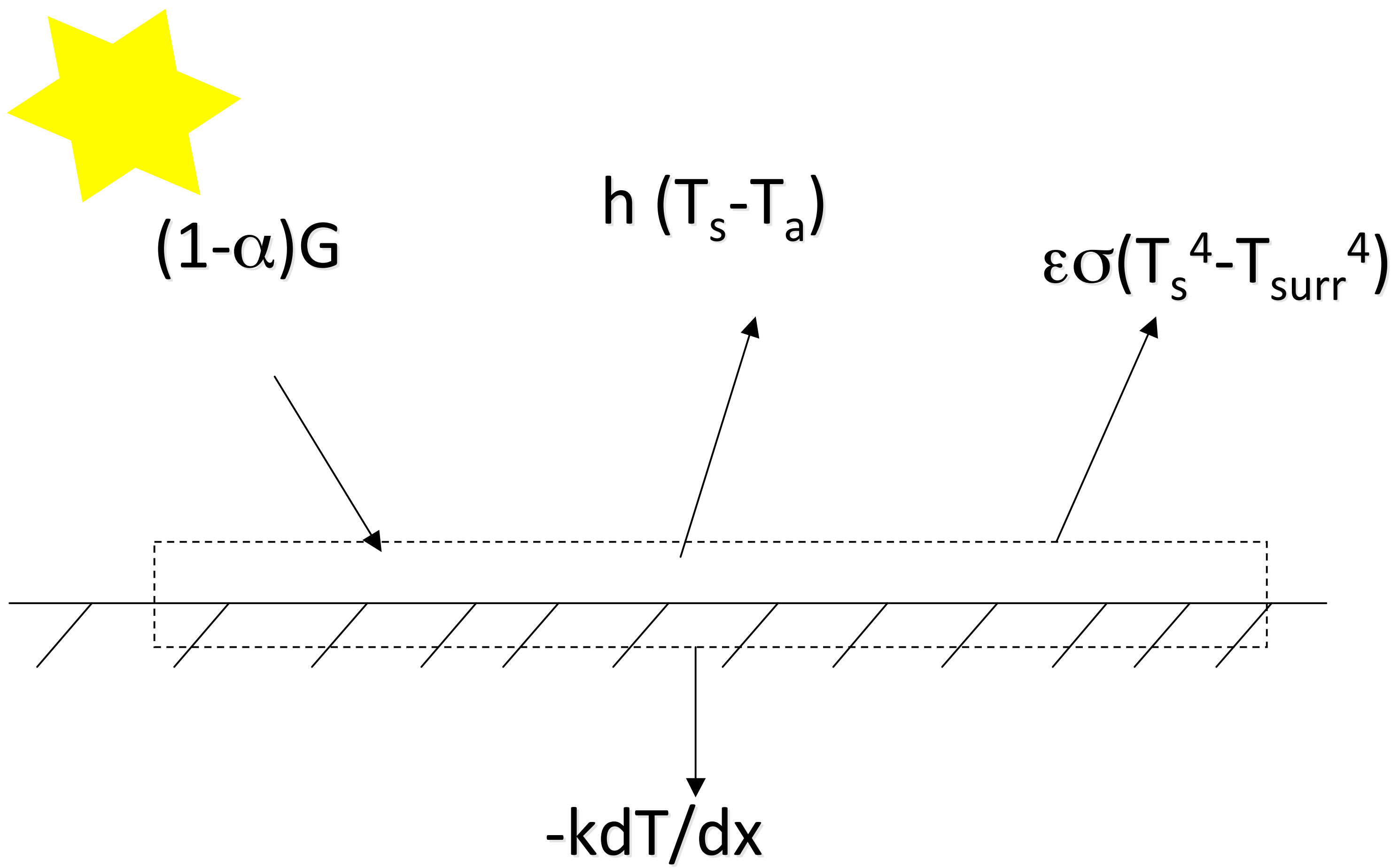
Rajib B. Mallick and Sankha Bhowmick

WPI and UMASS, Dartmouth

Outline

- Introduction
- Proposed approach
- Modeling
- Experiments
- Conclusions and Recommendations

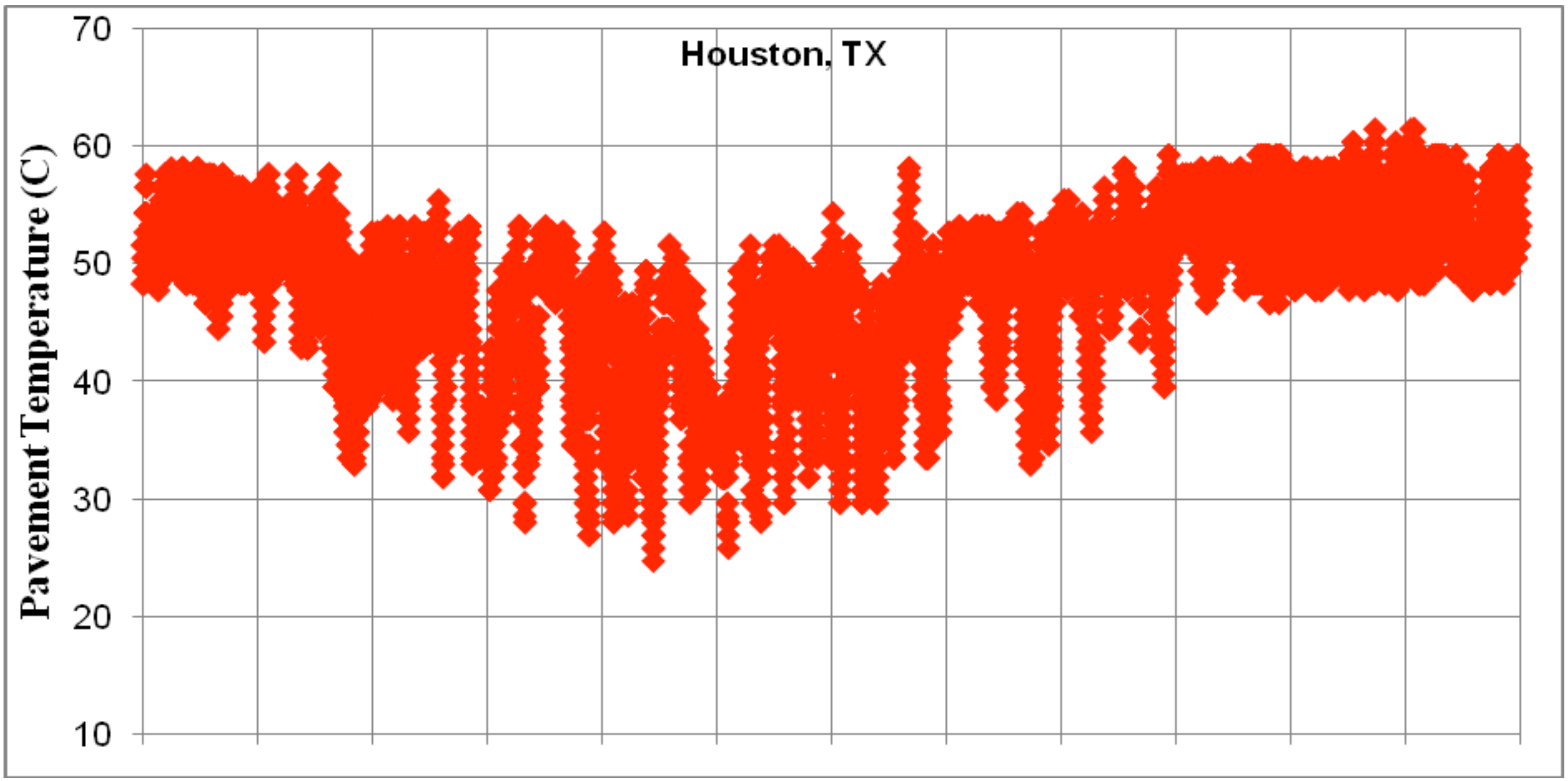
Energy Balance of Pavement



- Typically, peak temperature is about an inch below the pavement surface

Background

- Distribution of Annual Pavement surface temperature- predicted statistically



Background

City	Maximum Temperature (^oC)
Houston, TX	62
Jacksonville, FL	60
Albuquerque, NM	61
Reno, NV	61
Atlanta, GA	61
Nashville, TN	60
Los Angeles, CA	59

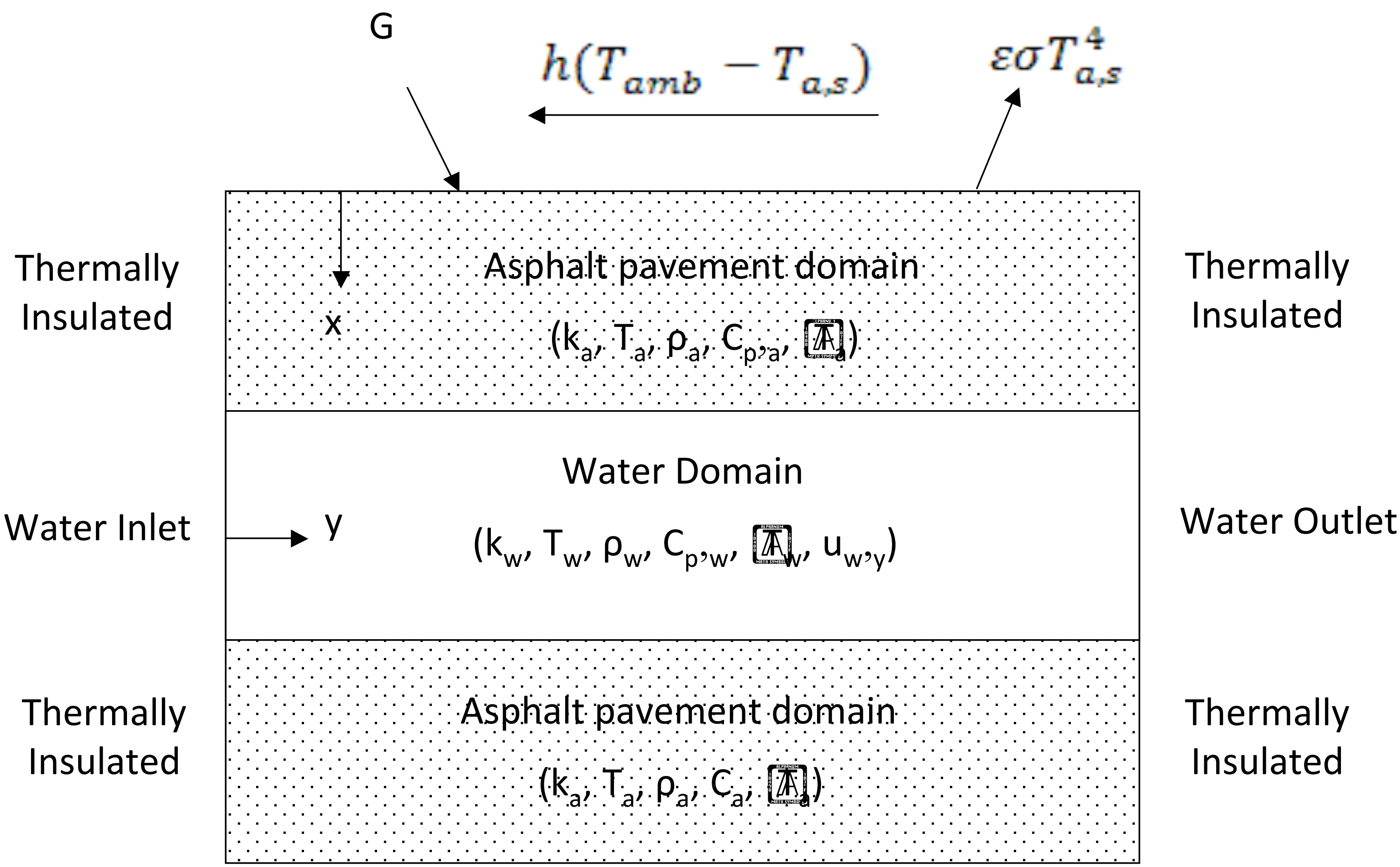
Literature

- “Cool pavements” have been proposed through alteration of albedo of the surface of the pavement
- Pomerantz et al, 2000, Kinouchi et al. 2004, Schindler et al. 2004, Kawakami and Kubo, 2008
- The evaporation of water in the pavement porous mixes could be used to keep the pavement cool
- Asaeda and Thanh, 2000

Proposed Approach

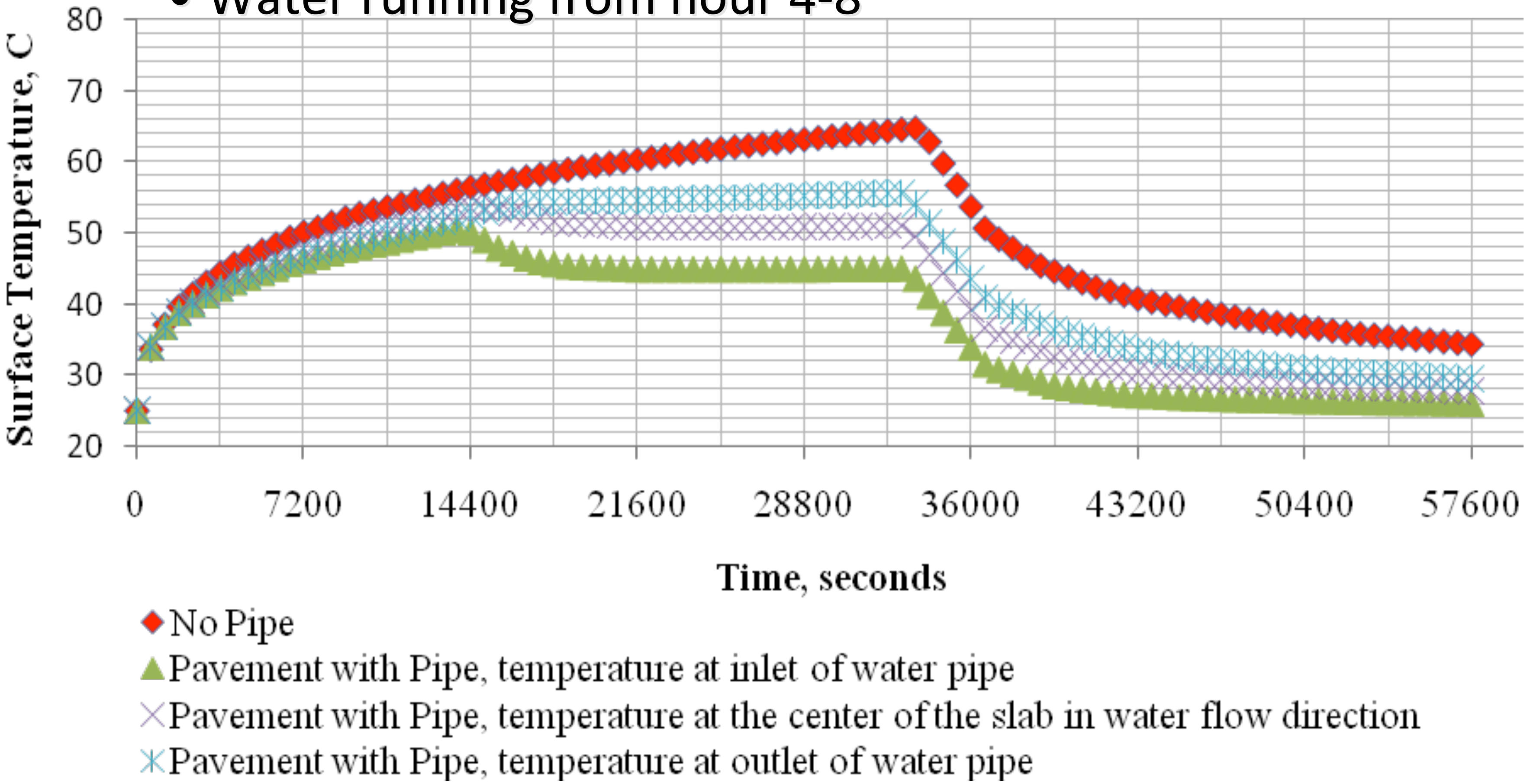
- Surface temperature of the asphalt pavement will be reduced due to the convective heat transfer of water flowing underneath it, which will decrease the back radiated energy emitted from asphalt pavement to the air.

Numerical Scheme

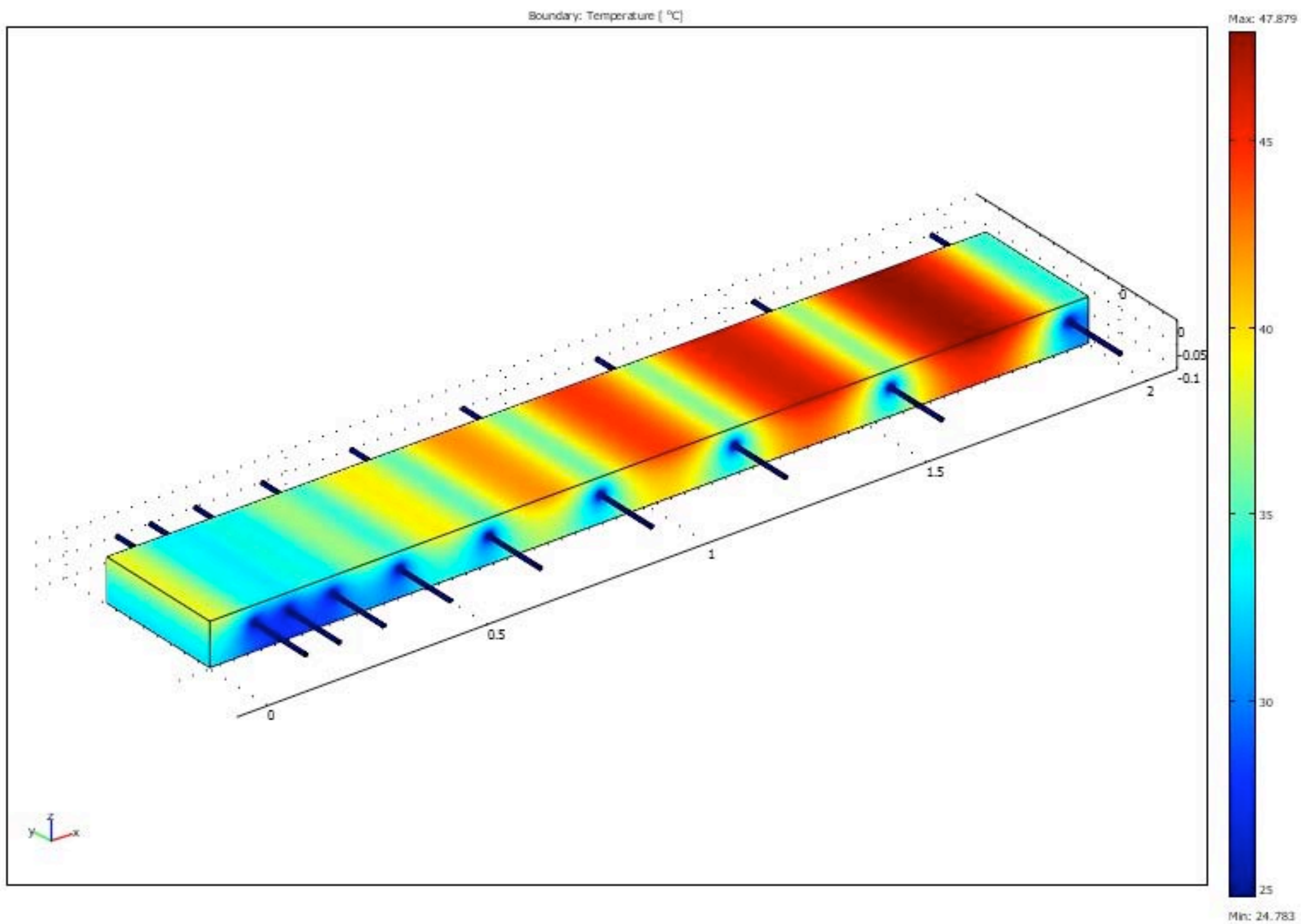


Results of Modeling: Pavement Surface Temperature

- HMA pavement
- Pipe 40 mm below surface
- Solar radiation for 8 hours
- Water running from hour 4-8

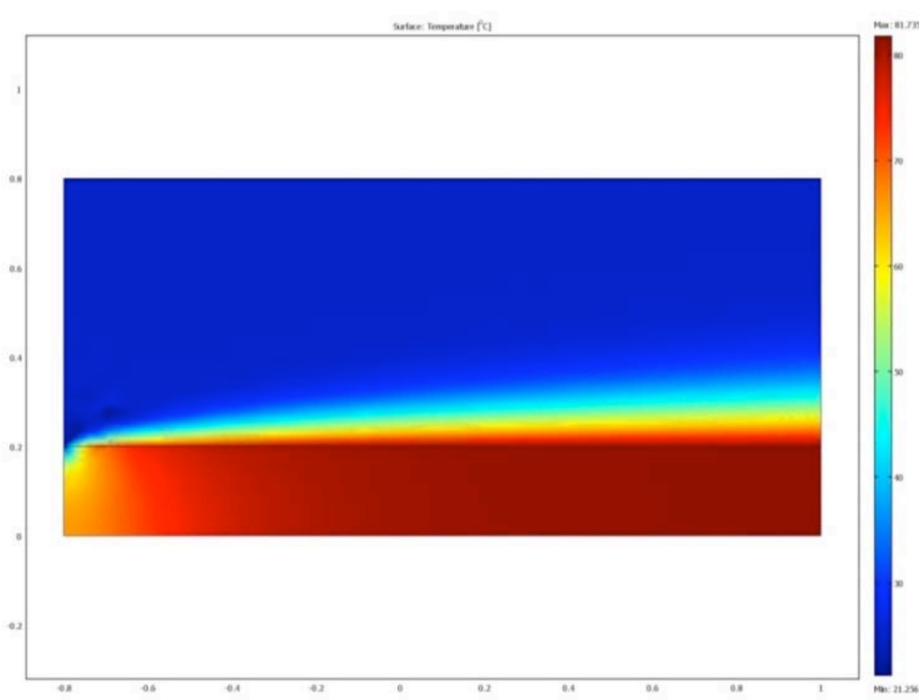


Pavement Surface Temperature
(Effect of pipe spacing)

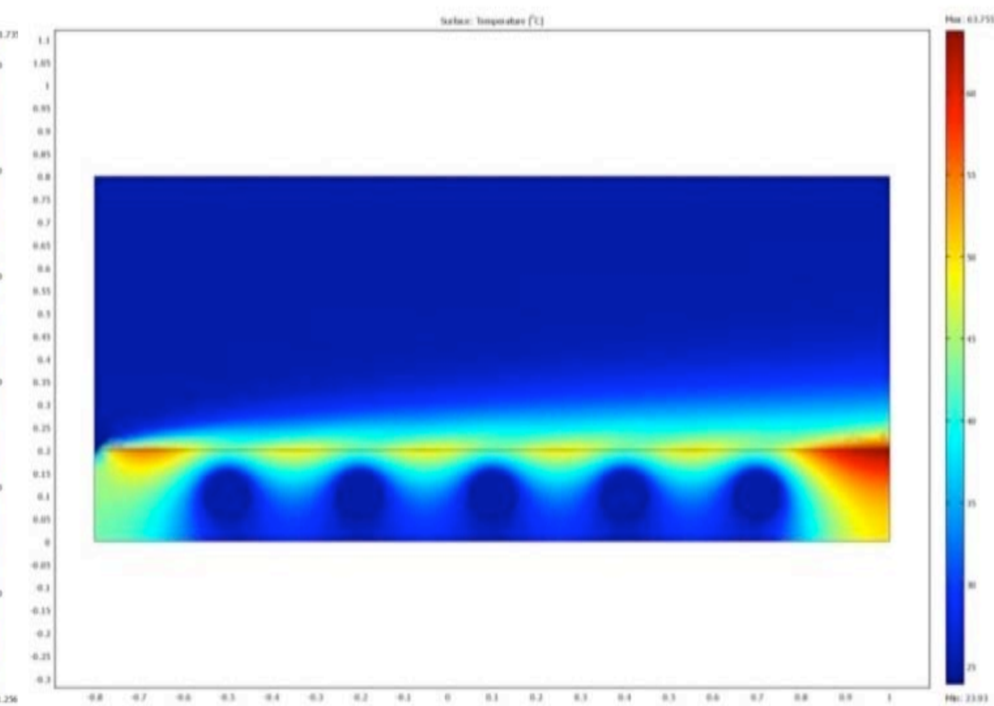


- Closer pipe spacing allows reduction in surface temperature

Boundary Layer Air Temperature



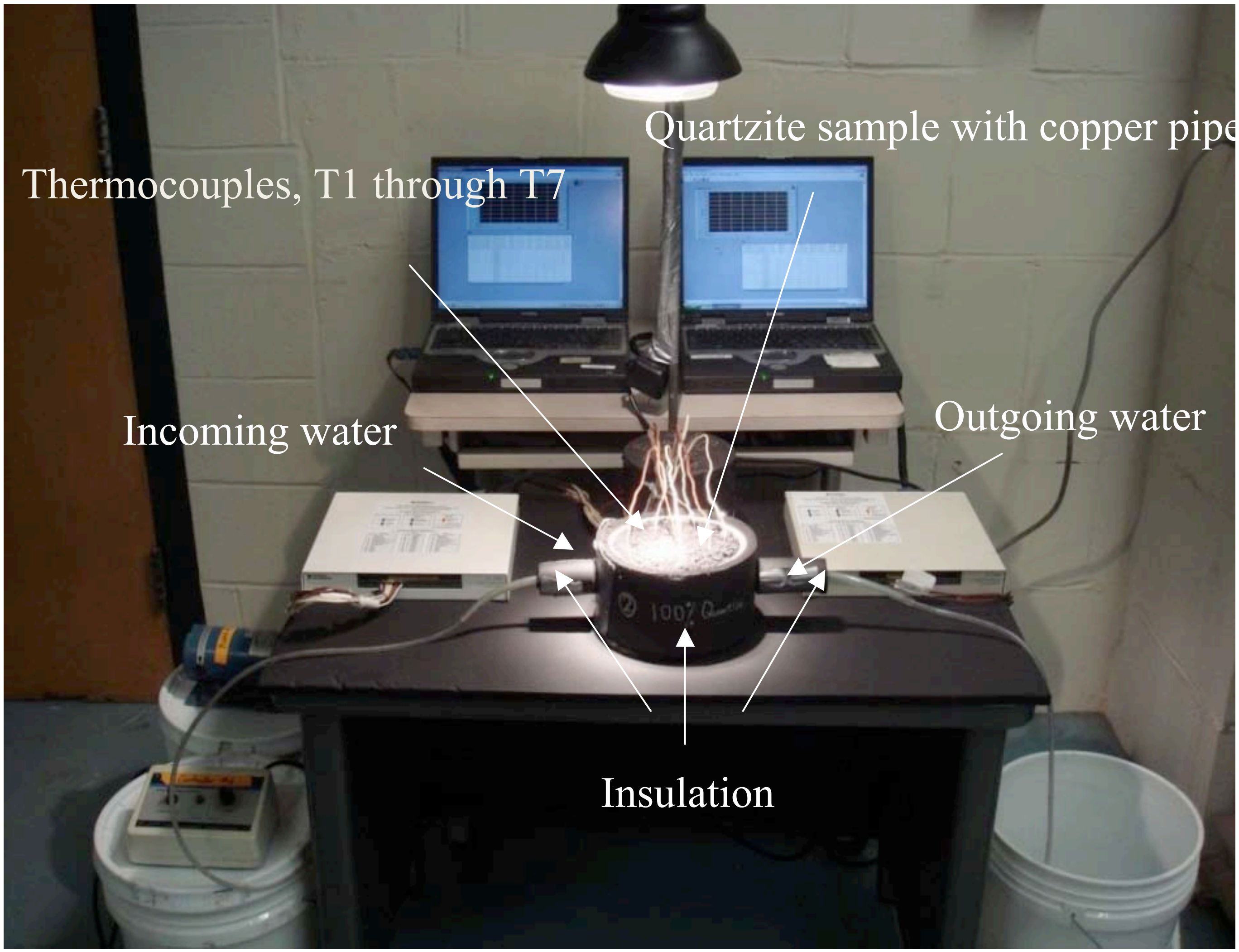
without water flow



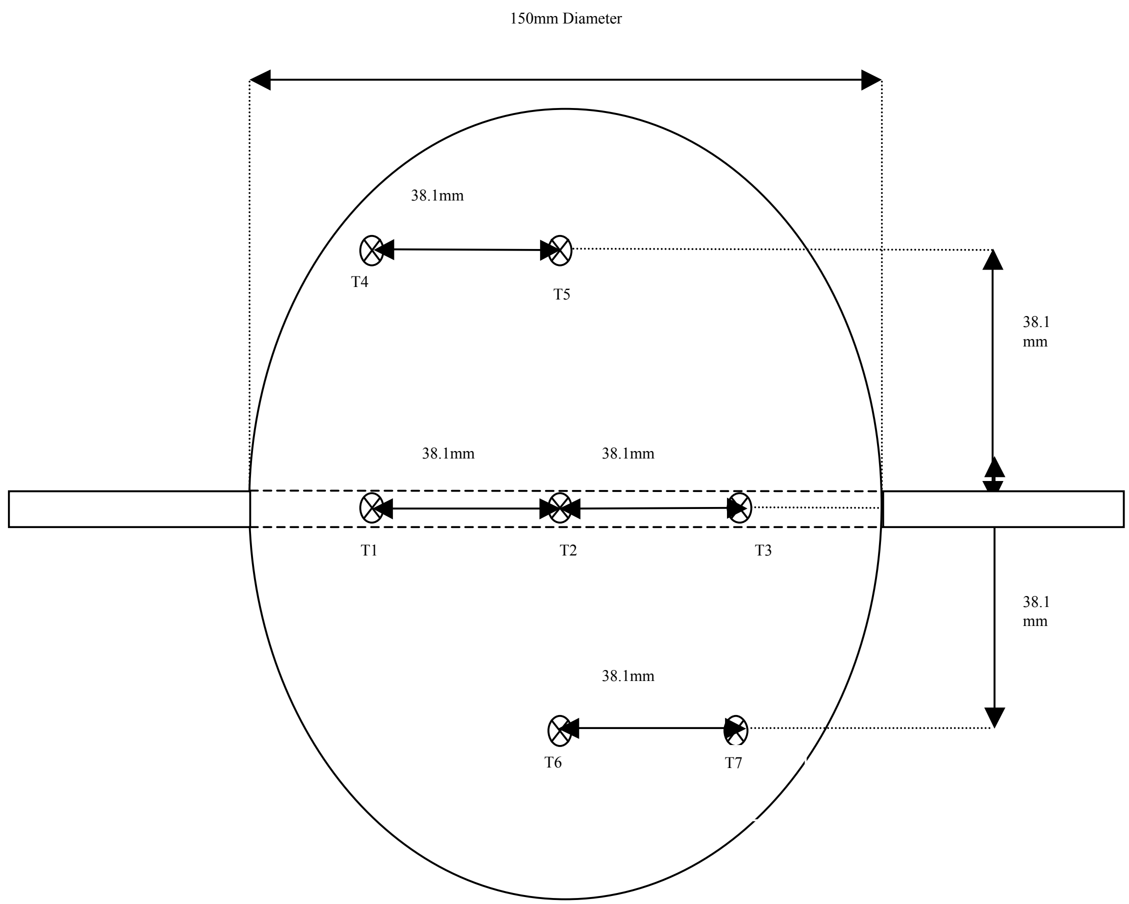
with water flow

- Simulation of the air boundary layer on top of the pavement
- Reduction of temperature in the BL; particularly the layer adjoining the pavement

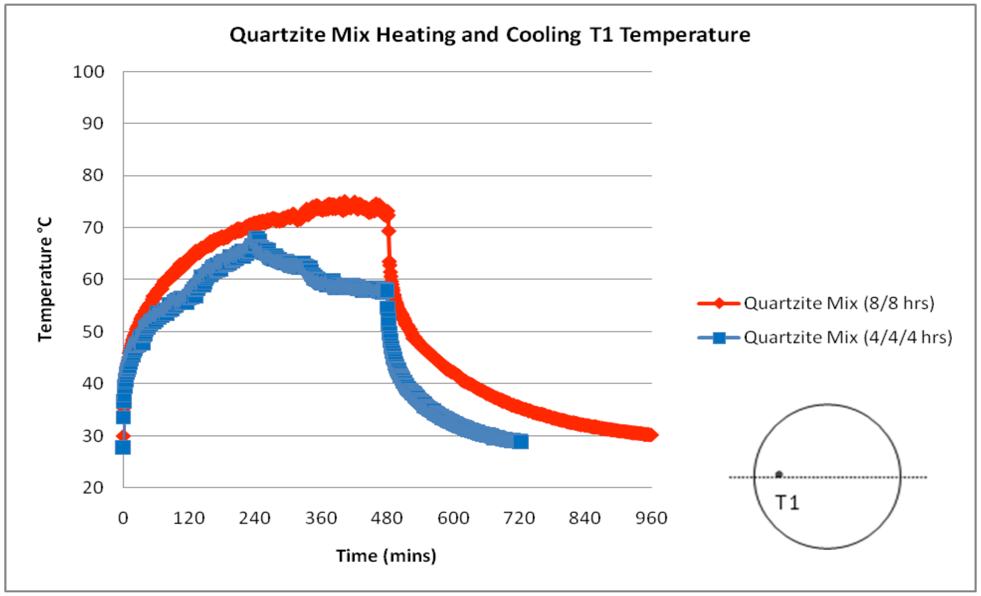
Laboratory Experimental Setup

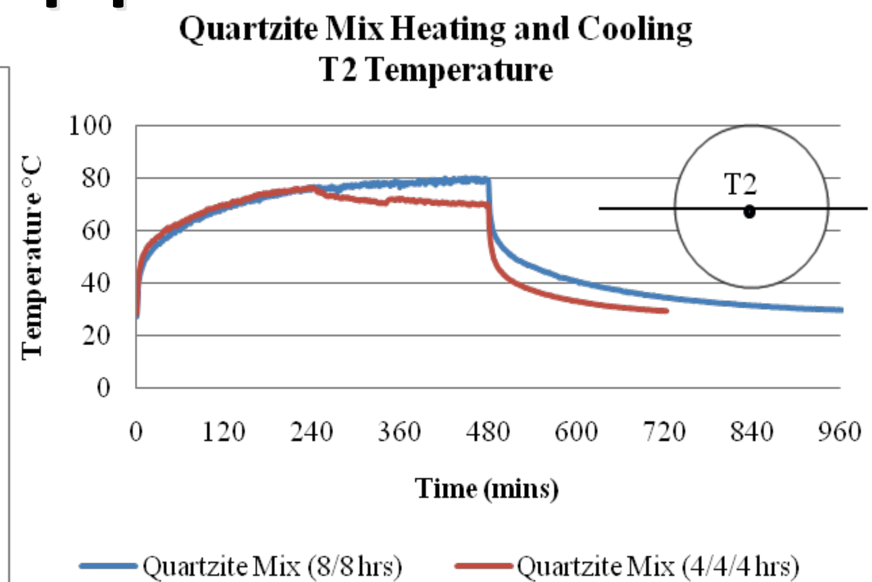


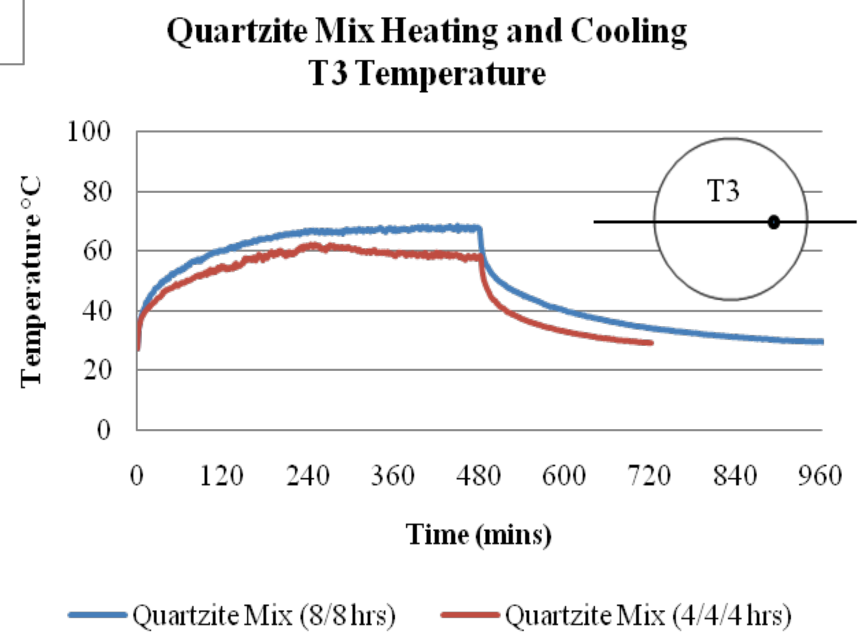
Surface thermocouple layout (Top view)



Surface Temperature Measurements: Above pipe

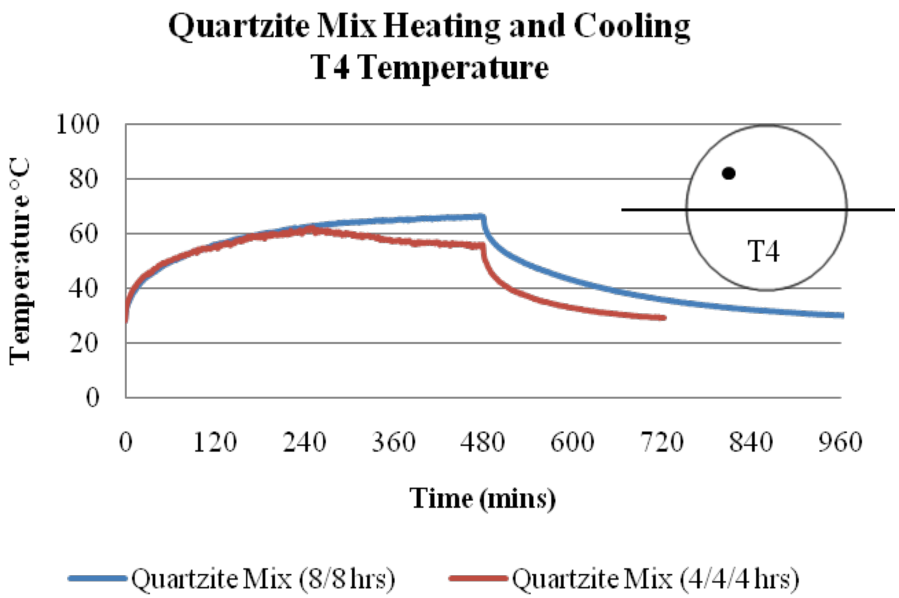


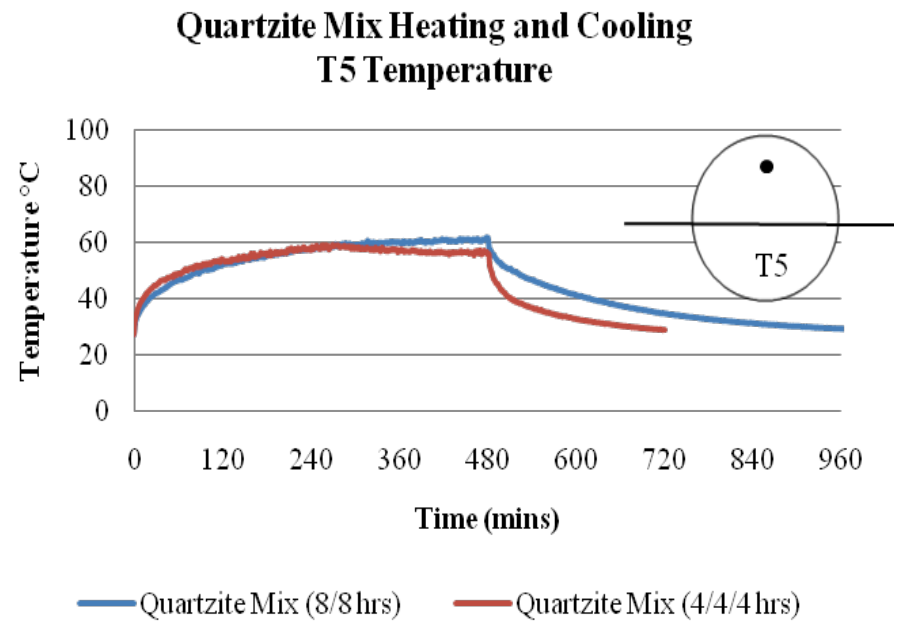


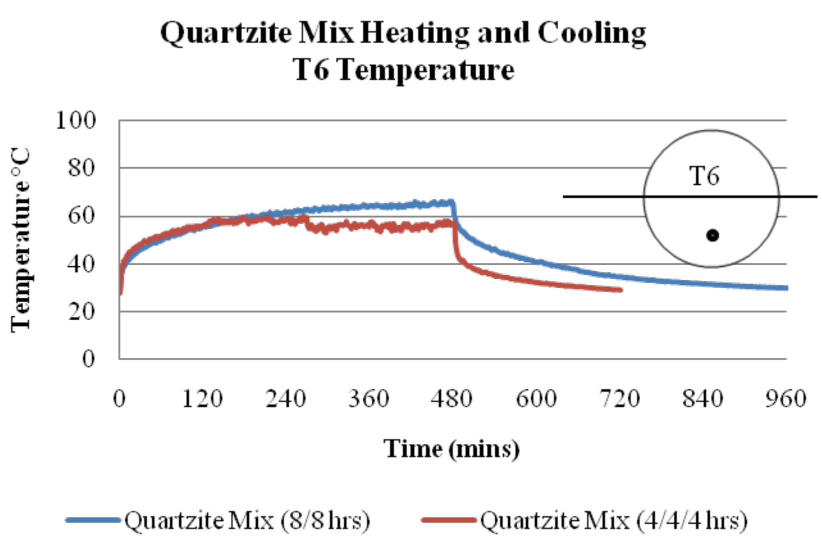


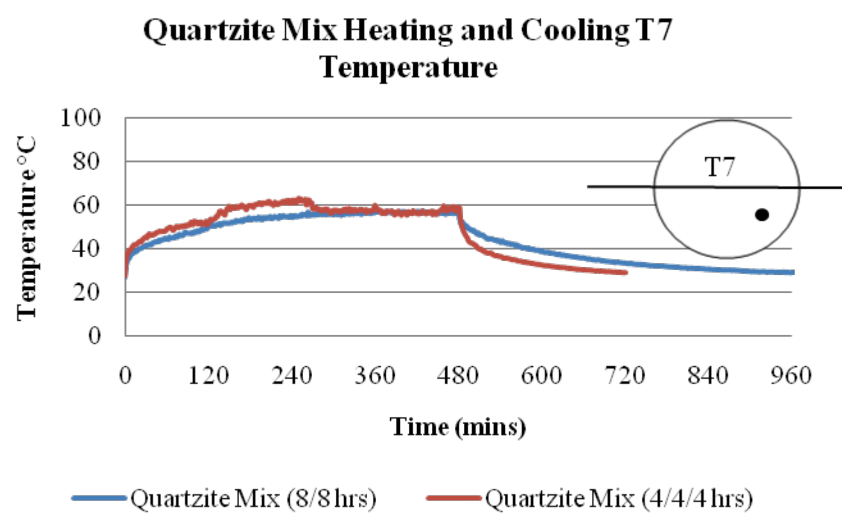
- Maximum surface reduction in temperature at entrance (T1)
- About 4°C cooling is available even at the exit (T3)
- About 80 mm length is cooled

Surface Temperature Measurements: Around the pipe







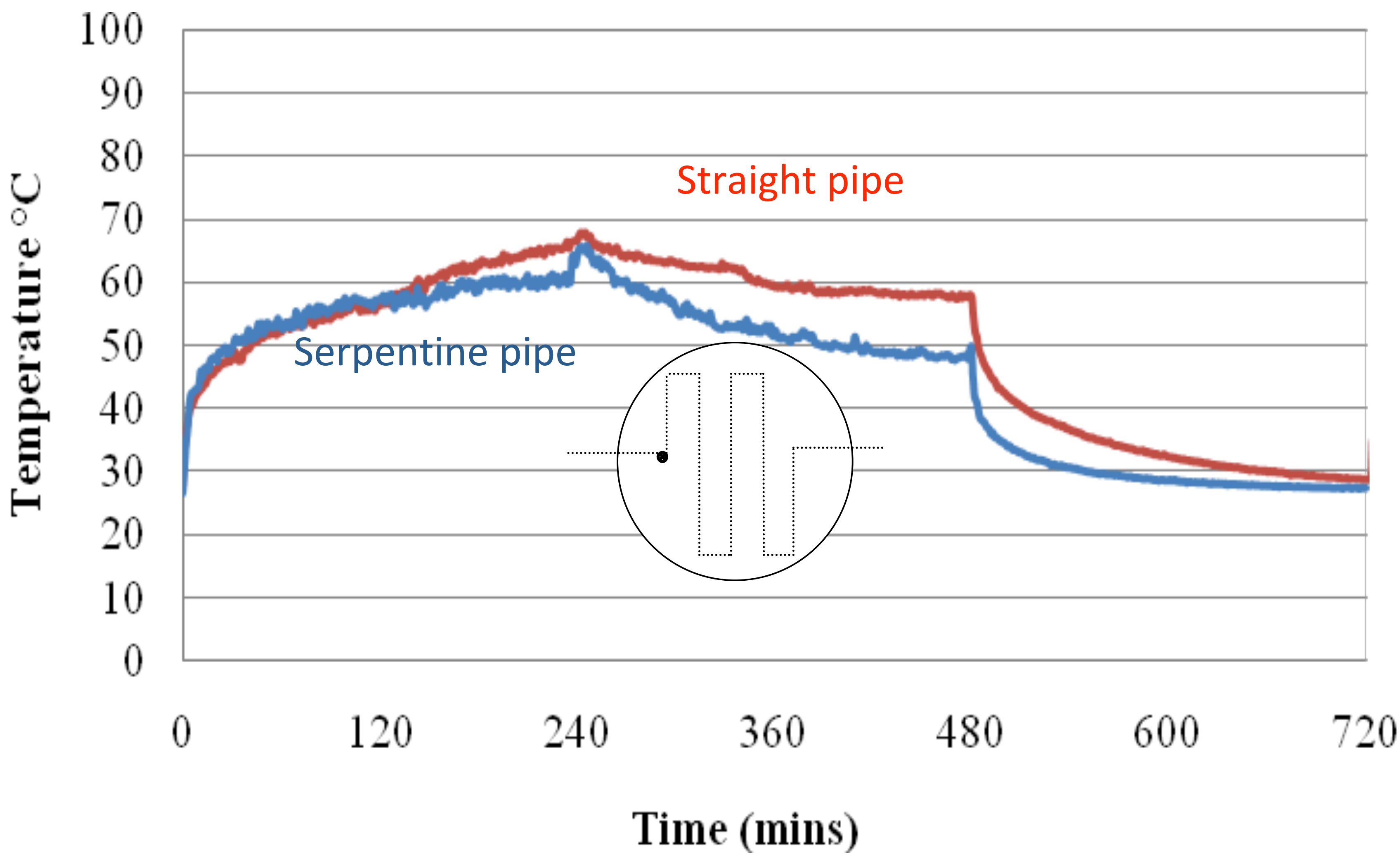


Surface Temperature Measurements: Summary

Thermocouple	T1	T2	T3	T4	T5	T6	T7
Max (no heating)	70.83	76.77	61.30	66.98	64.31	61.71	57.12
Minimum (with water flow)	57.40	72.09	56.33	57.32	58.94	55.69	55.10
ΔT (°C)	13.43	4.68	4.96	9.65	5.37	6.02	2.02

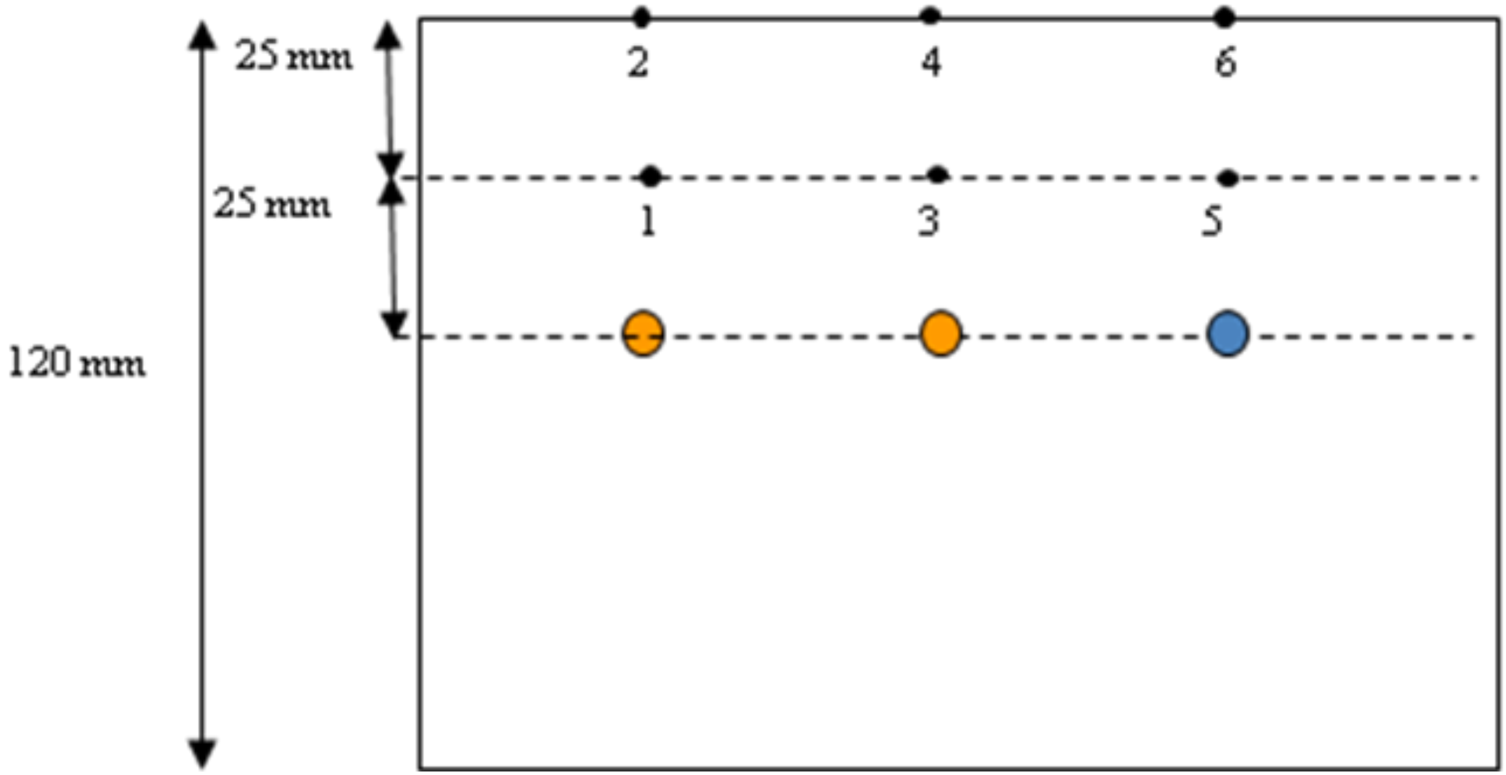
- Reduction in temperature ranged from 13.4^{o}C to 2.0^{o}C, for various thermocouple locations, T1 through T7, on the surface of the HMA sample
- About 9°C reduction in temperature is available at 38 mm away at the entrance
- Lowest reduction in temperature is 2°C at the hot end of the pipe

Pavement Surface Temperature (Serpentine Pipes)

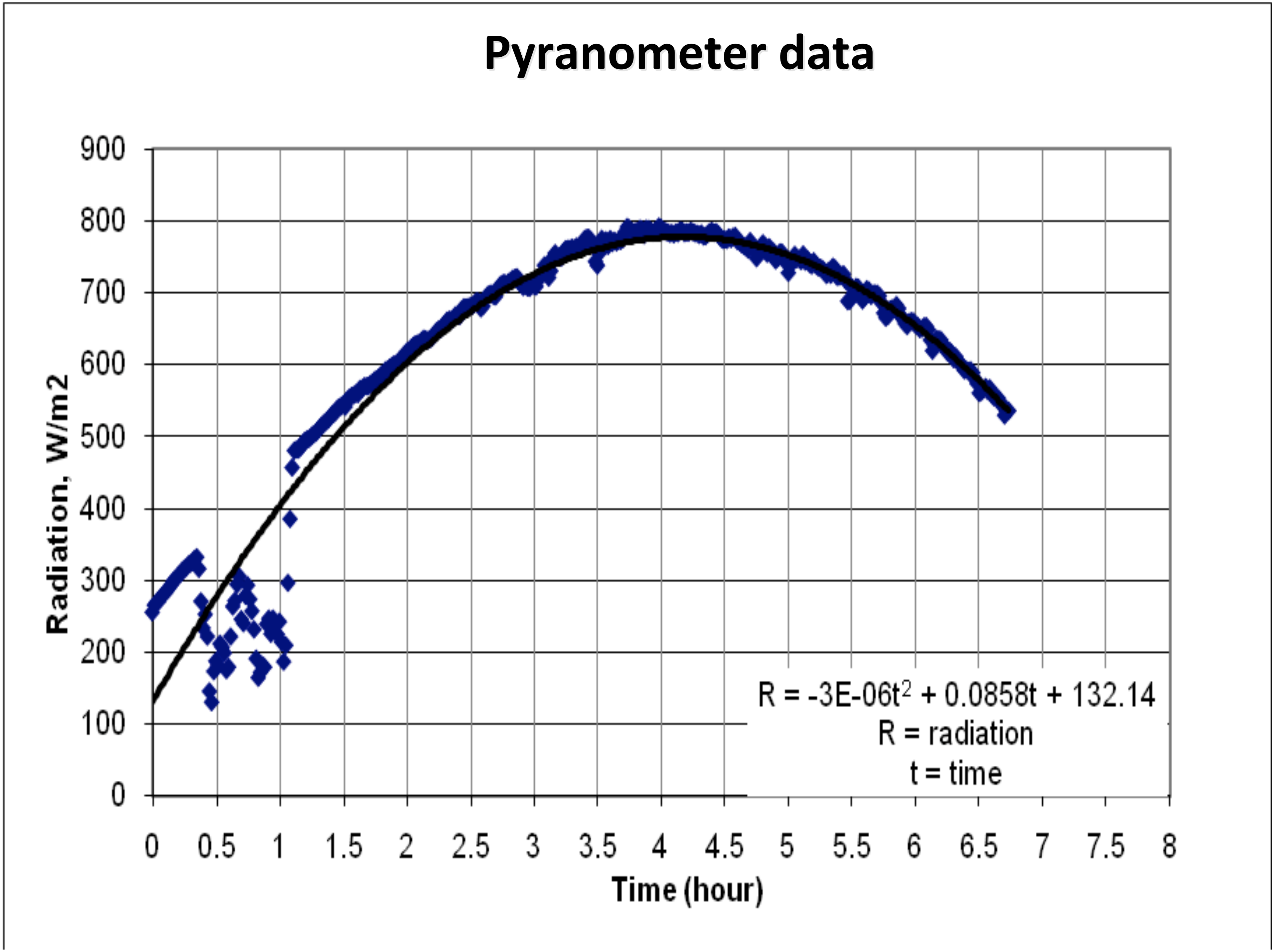


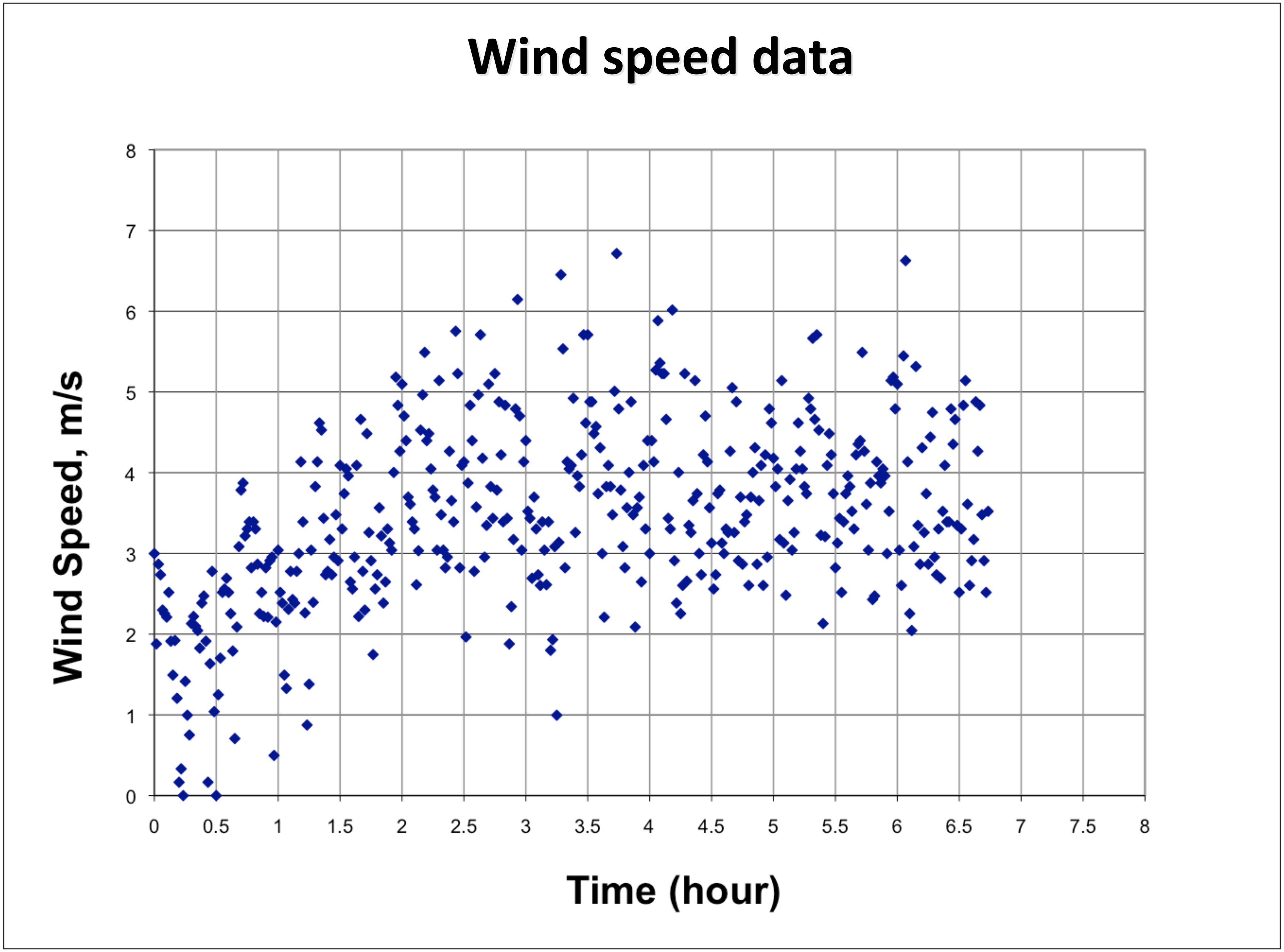
- Serpentine pipe allows further reduction in surface temperature

Large Scale Experimental Setup



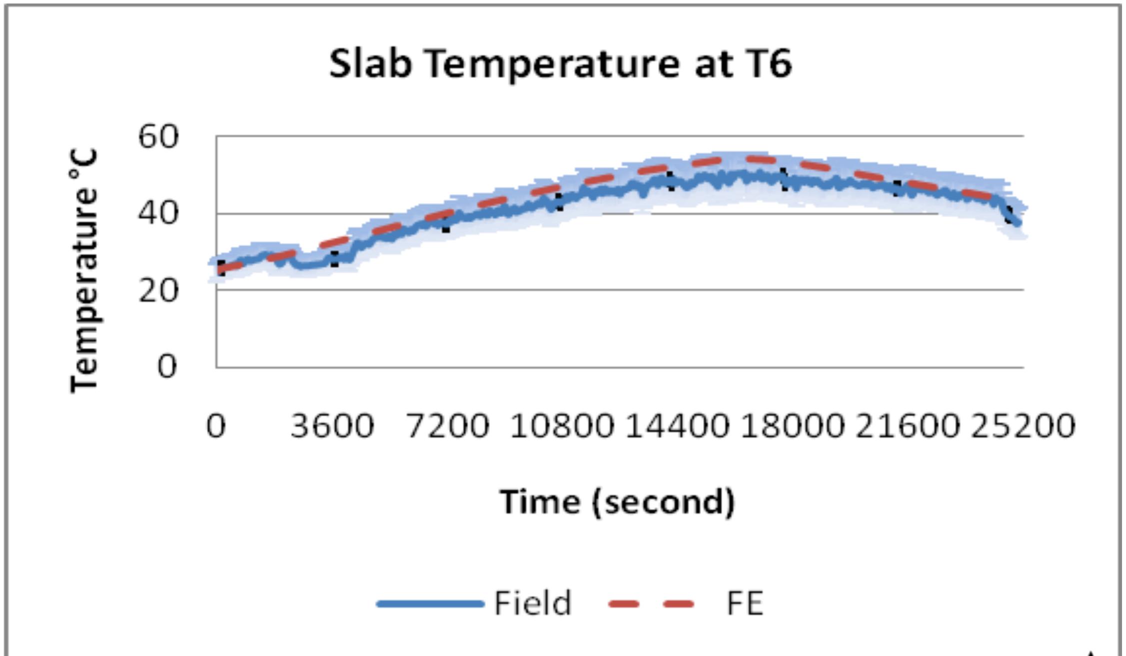
Time (hour/seconds)	Event
0 (0)	Start of solar radiation and wind
4.7 (17,040)	Start of water flow at 1 l/minute
5.3 (19,200)	Change flow of water to 2l/minute
5.8 (21,180)	Change flow of water to 3l/minute
6.5 (23,400)	Change flow of water to 4l/minute

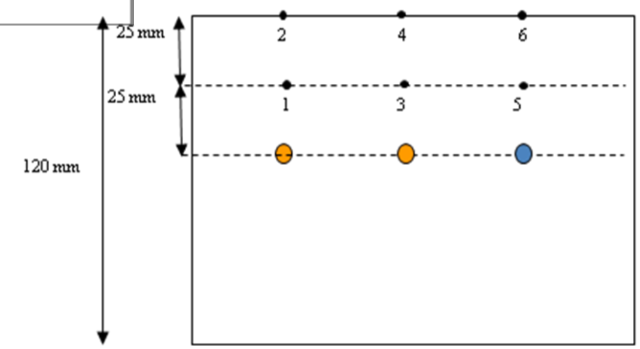

Pyranometer data
Radiation, W/m2
Time (hour)
R = -3E-06t2 + 0.0858t + 132.14
R = radiation
t = time
900
800
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8



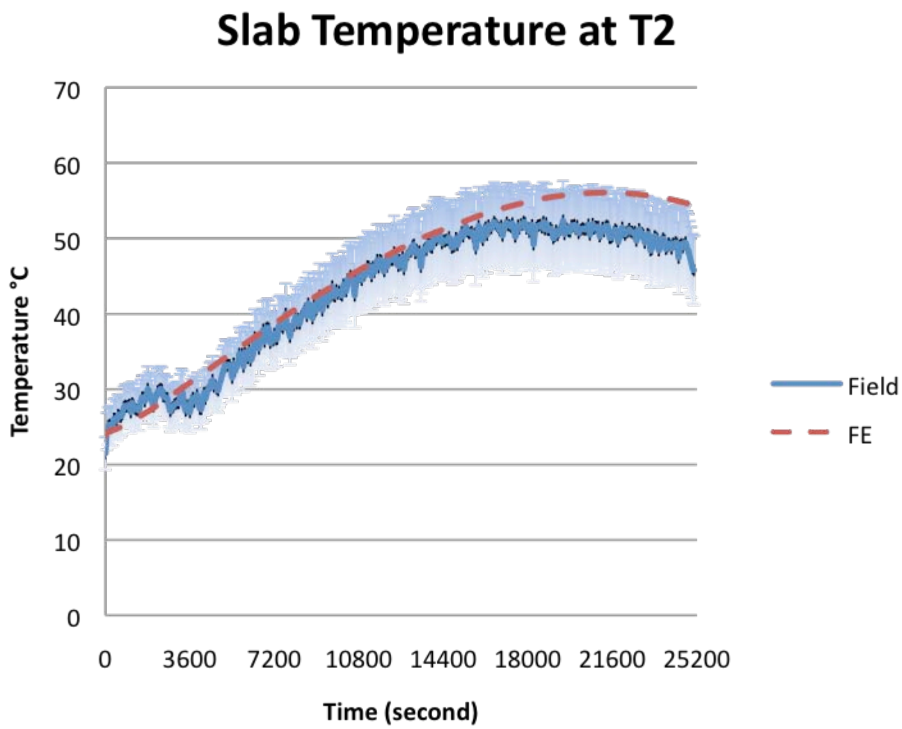
Wind speed data
Wind Speed, m/s
Time (hour)
0
1
2
3
4
5
6
7
8
0.5
1.5
2.5
3.5
4.5
5.5
6.5
7.5

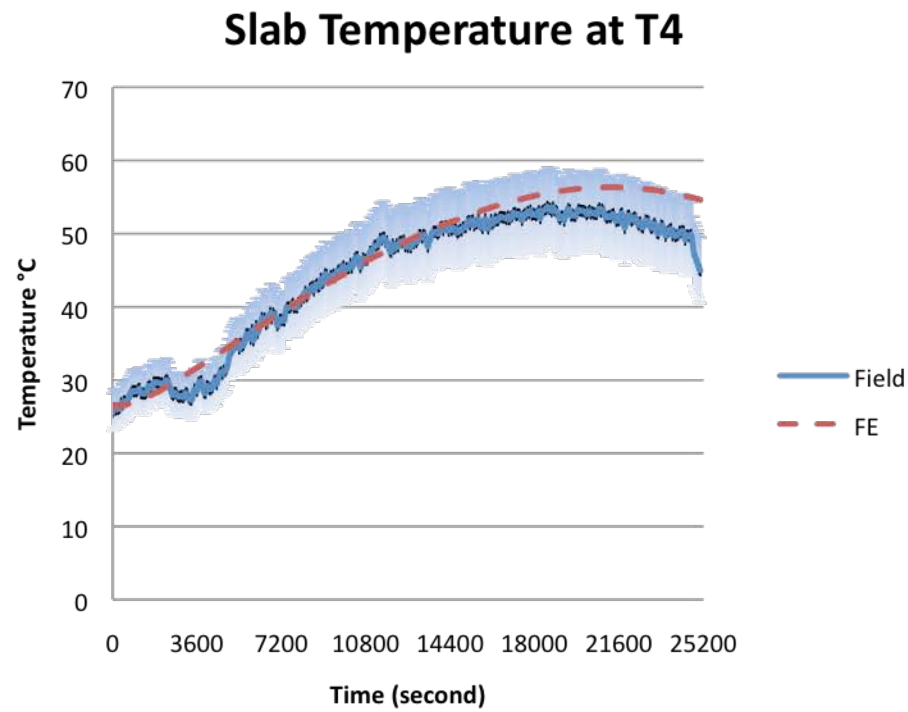
Large Scale Experimental Results





Large Scale Experimental Results





As in small scale, surface temperature can be lowered at some distance

Beneficial Effects

Reduction in 5°F(2.6 C) Air Temperature on Energy Consumption and 1 Hour/8 Hour Ozone Concentration (From MIST- Sailor and Dietsch, 2005)

- **Inputs**

Location: Houston; Mean Temperature: 73.4°F; Cumulative Degree Days (CDD): 2,810

Heating Degree days (HDD): 1,552; Typical maximum 1 hour ozone (ppb): 182

Typical maximum 8 hours ozone (ppb): 138

- **Outputs:**

Savings in energy consumption:

Post 1980 buildings

Electricity heated buildings: residential: 22%; office: 11%; Retail: 13%

Reduction in ozone concentration

For 1 hour ozone concentration -5.6 to -3.4 ppb

For 8 hour ozone concentration: -4.2 to -2.5 ppb

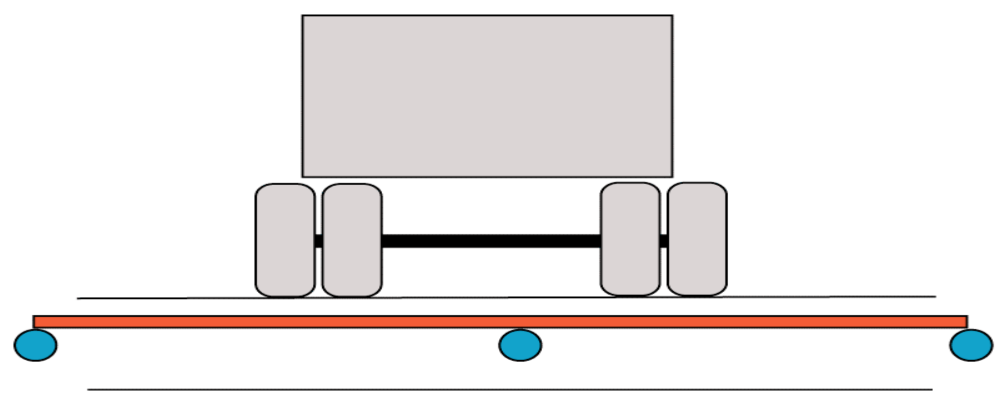
- **Equivalent to an increase of albedo by 0.5**

Additional Benefits

- Extracting the heat stored in pavements can be used for
- Process heating
- Feed-water for other applications or
- Heat exchanger fluid for heating cycle.
- The water at high temperature could be stored in insulated chambers

Practical problems

- Effect of pipes on pavement performance,
- Effect of traffic and pavement load on the pipes
- Maintenance of piping system, and
- Resistance of the piping material to high temperature of lay down of HMA



Conclusions and Recommendations

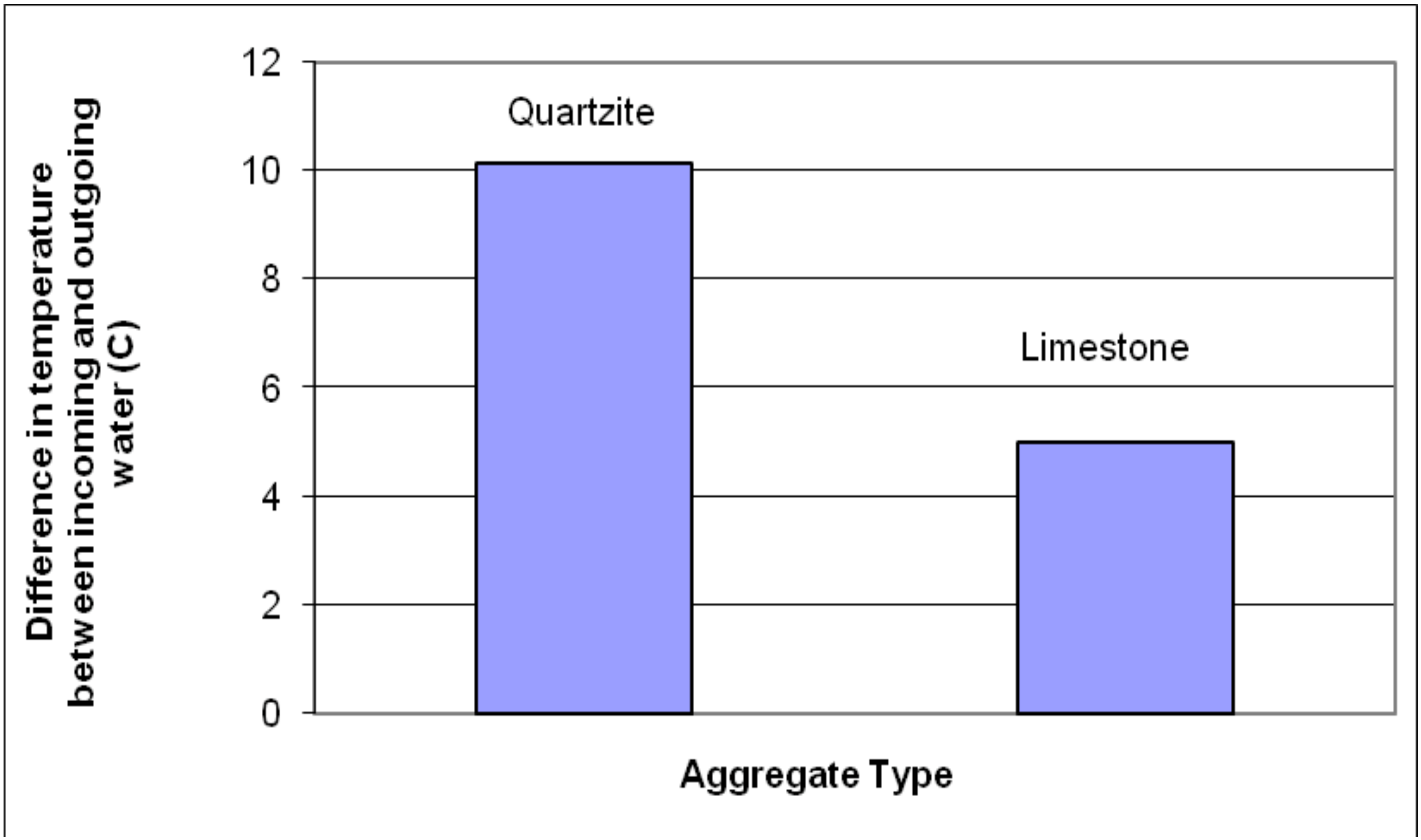
- Both finite element modeling and experimental results have proven the feasibility of using heat energy harvesting as a good method of reducing pavement temperature.
- Reduction in the temperature of the pavement is dependent on the location and spacing of pipes.

Conclusions and Recommendations

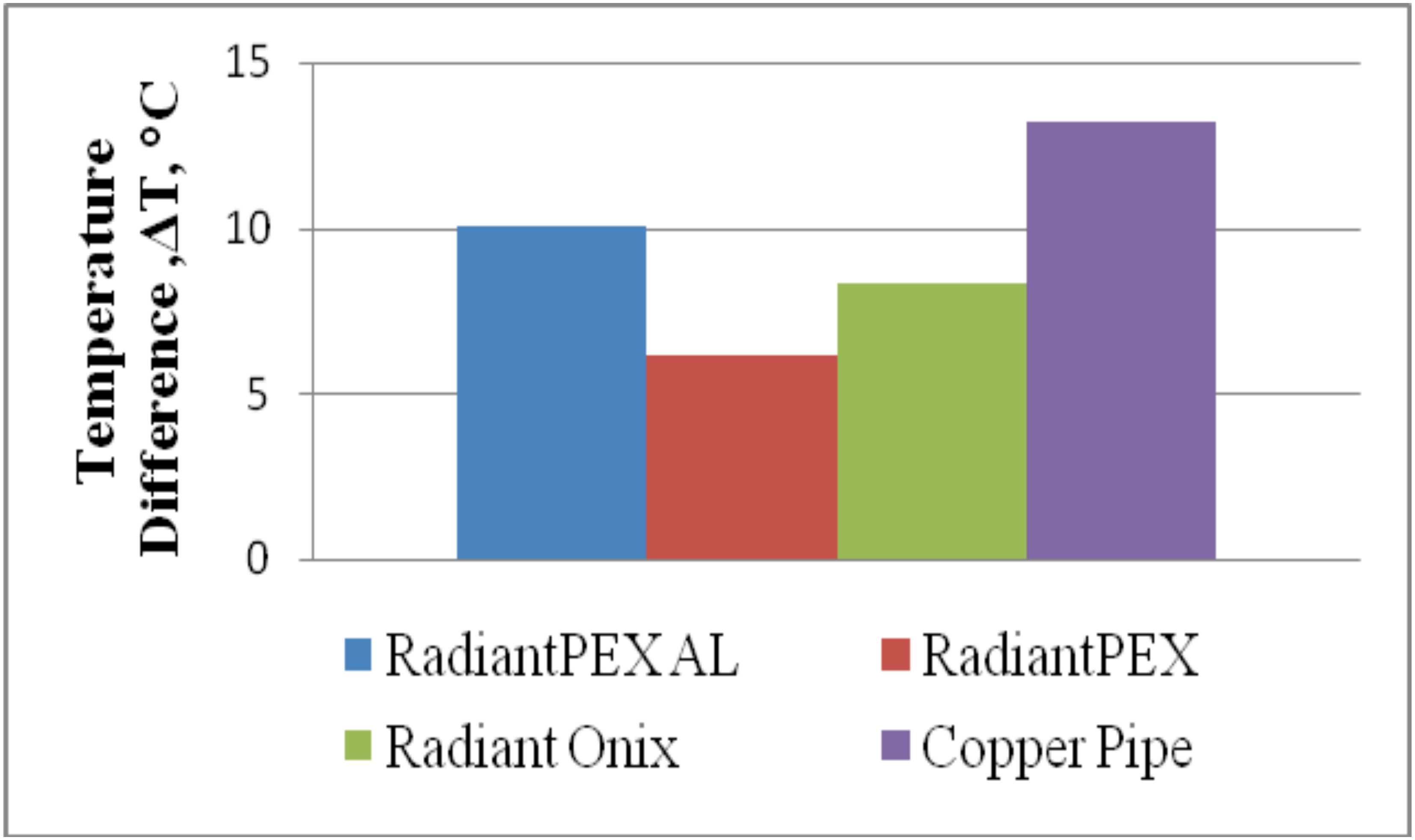
- The location and spacing of pipes required for optimum results are of practical concern.
- Full scale studies in the areas with high solar radiation are needed to understand practical issues and optimize the various components of the proposed system.


Thank you!

Effect of Aggregate



Effect of Pipe Material



Economic Feasibility

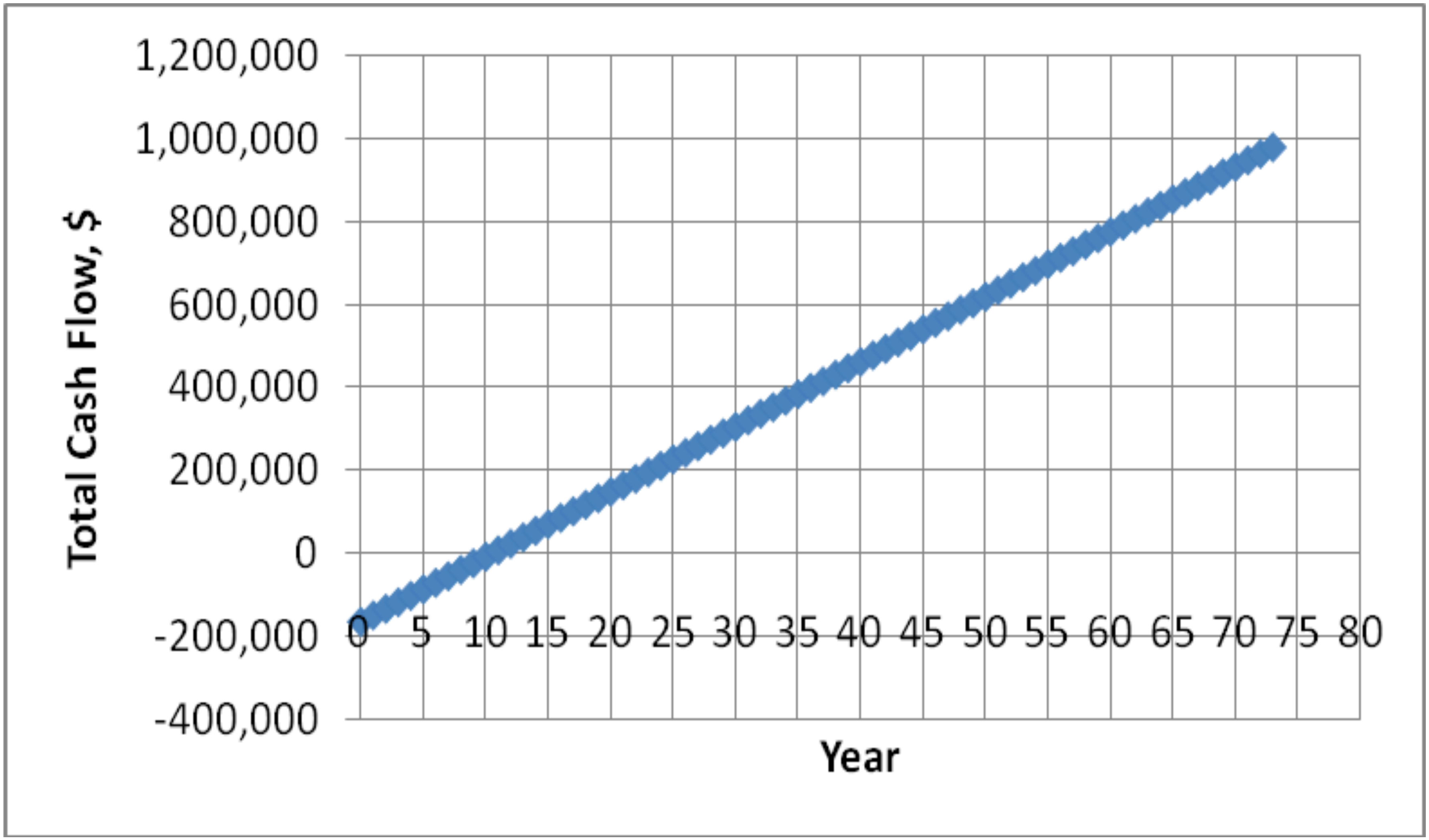
- Location
- Investment
- Extracted energy
- Used NOAA information

	1	2	3	4	5	6	7	8	9	10
1	**Input Values Below**				Example	Direction	GMT/UTC		Direction	Example
2	Latitude:	8.50	degrees		USA	North	+	-	South	South Africa
3	Longitude:	-76.95	degrees		USA	West	+	-	East	India
4	UTC Offset:	-5.5	hours		USA	West	+	-	East	India
5	Depth Requested:	40	mm				Sign Convention			
6										
7	**Input**		**Temperature at Depth °C**							**Hour of Year**
8	**YRMODAHRMN**	**Tair (°F)**	**Surface**	**25 mm**	**50 mm**	**75 mm**	**100 mm**	**125 mm**	**Requested Depth**	
9			67	68	69	70	71	72	73	75
10	200709010000	73								
11										

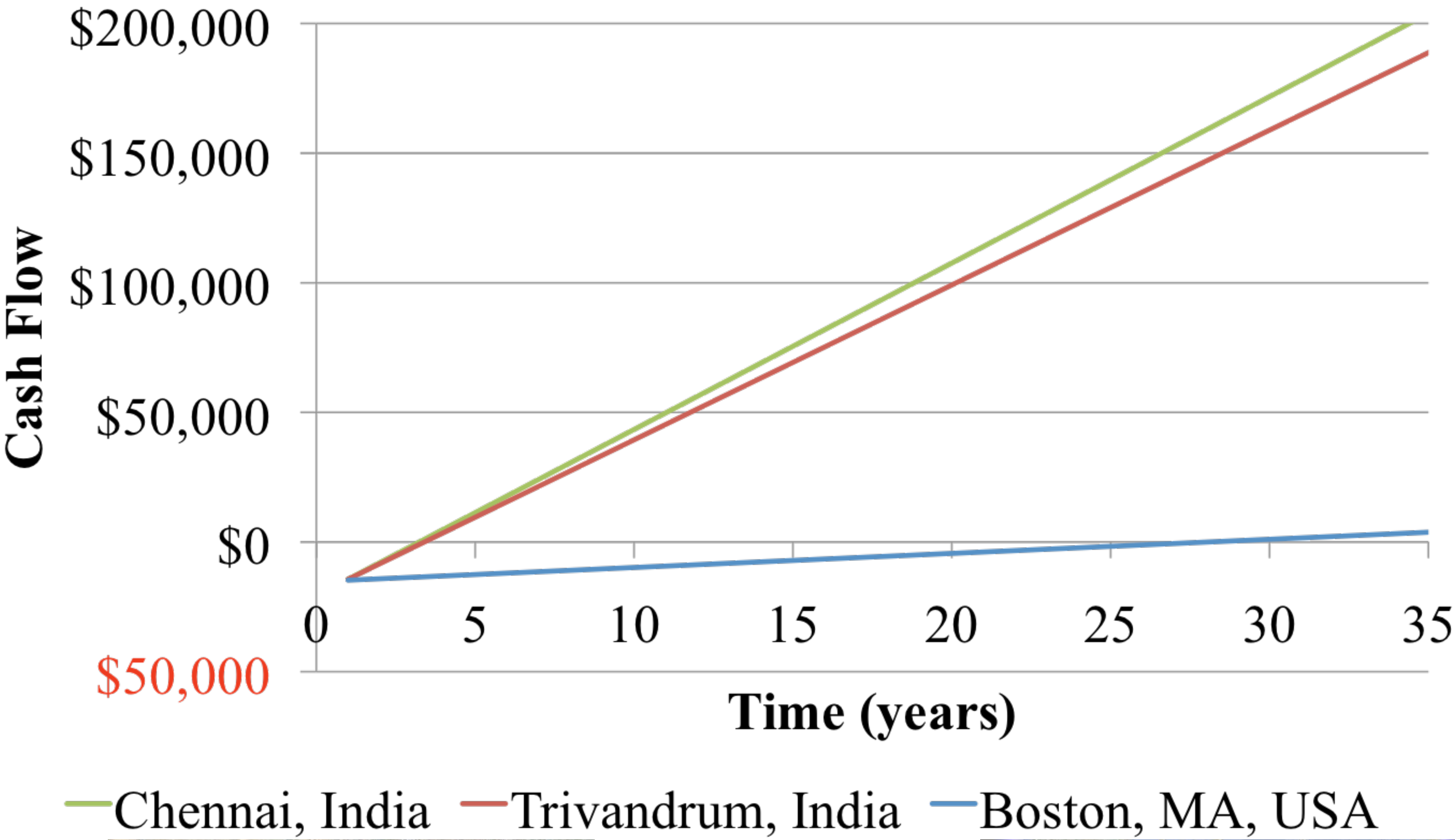
Pavement-Air Temperature Model

	1	2	3	4	5	6	7	8	9	10
1	**Input Values Below**				Example	Direction	GMT/UTC		Direction	Example
2	Latitude:	8.50	degrees		USA	North	+	-	South	South Africa
3	Longitude:	-76.95	degrees		USA	West	+	-	East	India
4	UTC Offset:	-5.5	hours		USA	West	+	-	East	India
5	Depth Requested:	40	mm				Sign Convention			
6										
7	**Input**		**Temperature at Depth °C**							**Hour of Year**
8	**YRMODAHRMN**	**Tair (°F)**	**Surface**	**25 mm**	**50 mm**	**75 mm**	**100 mm**	**125 mm**	**Requested Depth**	
9			**67**	**68**	**69**	**70**	**71**	**72**	**73**	**75**
10	200709010000	73	27.64	28.11	28.50	28.86	29.21	29.52	28.35	5856.00
11	200709010300	76	27.24	27.95	28.59	29.16	29.69	30.15	28.34	5859.00
12	200709010600	84	27.07	27.89	28.62	29.29	29.89	30.41	28.34	5862.00
13	200709010900	85	36.31	34.88	34.13	33.79	33.69	33.67	34.37	5865.00
14	200709011200	81	53.76	48.48	44.99	42.75	41.27	40.12	46.21	5868.00
15	200709011500	79	58.26	53.40	49.83	47.35	45.58	44.10	51.11	5871.00
16	200709011800	78	47.63	47.58	46.86	46.09	45.37	44.56	47.18	5874.00
17	200709012100	76	36.35	36.79	36.86	36.87	36.87	36.77	36.85	5877.00
18	200709020000	75	30.25	30.95	31.46	31.89	32.27	32.57	31.27	5880.00
19	200709020300	78	27.74	28.54	29.23	29.83	30.37	30.83	28.97	5883.00
20	200709020600	85	26.70	27.55	28.31	28.98	29.59	30.11	28.01	5886.00

Houston, TX



1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
-200,000
-400,000
Total Cash Flow, $
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Year



Need more info.???